General test specification

OB_TC_R014 rev. 005

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OPTIMAT BLADES

TC

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Change record

Issue/revision	date	Pages	Summary of changes
0	07.01.04	All	New document
1	30.01.04	All	- Strain gauge measurement revised - Temperature measurement revised - Chapter 6.4 added
2	25.03.04	9,10,11	- Load levels added MD R=10 - Load levels changed UD90° R=-1 - Load levels corrected UD90° R=10 - References added
3	02.07.04	9,10,11	Definitions of load level 1 changed (1.000 cycles to 5.000 cycles)
4	30.05.05	10,11,12	- Load levels added UD90° R=0.1 - 2nd set of load levels introduced for UD90° R=-1 and UD90° R=10 - Load levels added MD R=-0.4
5	07.09.05	12	Load level 2 for UD90° R=10 corrected

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1 Introduction

This report describes the general test procedures used within all Task Groups.

2 Materials

Two reference materials of glass fiber reinforcement are supplied by LM Glasfiber A/S for the project. The first one is a single-layer unidirectional material of non-woven glass rovings from PPG with a minor amount of off-axis reinforcement. The second one is a biaxial material made of non-woven glass rovings from PPG as well. The build-up consists of two layers arranged in +45° and -45° direction and stitched together with a polyester yarn.
The resin used for infusion is the epoxy resin Prime 20 with slow hardener from SP Systems.
Detailed information about the materials is given in [1].

3 Laminates

Two standard laminates, a unidirectional laminate (UD) and a multidirectional laminate (MD) are part of the experimental work in all Task Groups.
The lay-up of the UD laminate consists of 4 layers of the UD reference material with laminae thickness of 0.88 mm yielding to a total nominal thickness of 3.52 mm.
The lay-up of the MD laminate consists of 5 layers of the biaxial reference material (±45º) inter-spaced with four layers UD. Thickness of the ±45 -layers is 0.61 mm and for the UD 0.88 mm as before. Total nominal thickness of the MD laminate is 6.57 mm.
Laminates are fabricated by infusion of the dry laminate package with epoxy resin by vacuum assisted resin transfer moulding. After initial curing at room temperature laminates are post-cured at 80°C for 4 hours.

4 Test specimens

Two geometries are used in general for the standard Optimat specimen made of the two laminates. The geometries for the standard UD specimen and the standard MD specimen are shown in Figure 1 and Figure 2 respectively. The UD specimen is used for 0° and 90° lay-up as well.

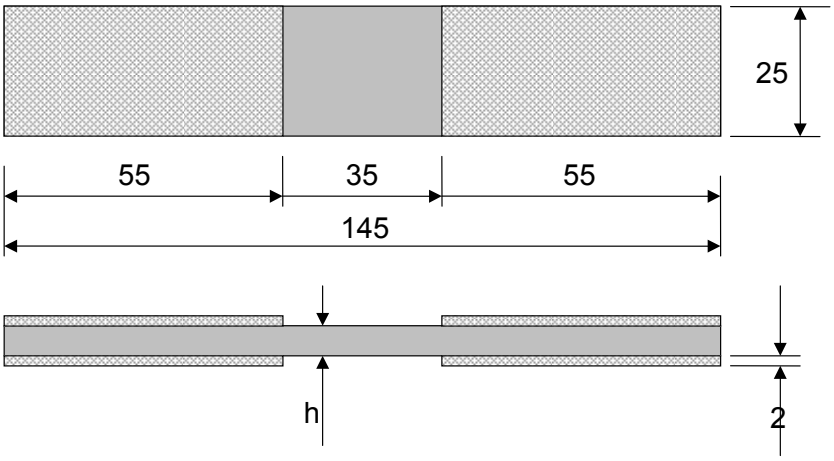

Figure 1: Optimat Blade specimen (UD)

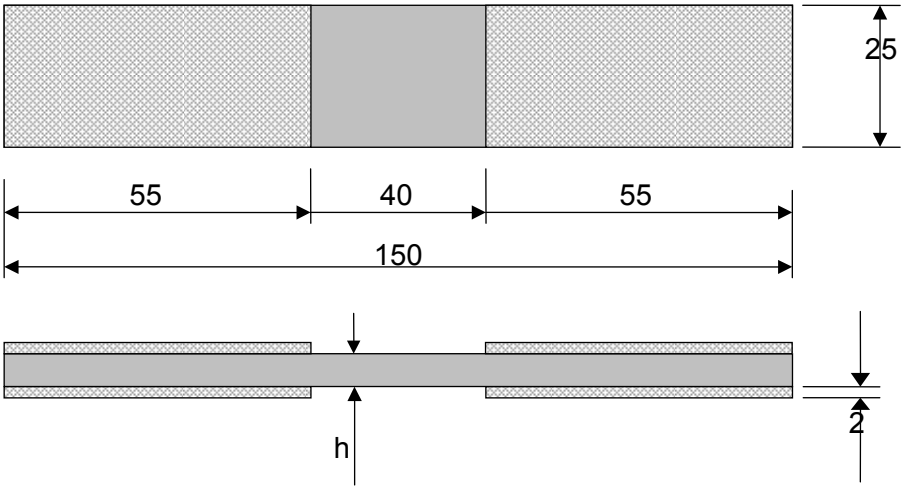

Figure 2: Optimat Blade specimen (MD)

5 Test procedures for static tests

5.1 General remarks

Each specimen has to be investigated by eye for any irregularities or damage. The alignment of the tabs has to be checked with a planar tool. Width and thickness of the specimens has to be measured with an accuracy of 0.01 mm.

5.2 Tensile testing

Tensile tests on the Optimat specimens are carried out according to ISO 527/4(5) standard. Standard test machines with hydraulic or mechanical grips are to be used. If hydraulic grips are used, the applied grip pressure should be recorded. Load has to be applied displacement-controlled and test speed amount to 0.25 mm/min. Strain in loading direction is measured with strain gauges (recommended gauge length 6 – 10 mm) or extensometer, and strain in transverse direction is measured with a single strain gauge (recommended gauge length 6 – 10 mm) placed on one side of specimen, or with transverse extensometer. Strain measurements should be set to zero before closing of the second clamp to determine initial bending of the specimen. Elastic properties of undamaged material are measured within applied strain of 0.05%-0.25%.
The required measurements are given in Table 1 and the required information for reporting to OptiDat in Table 2.

No.	Description
1	Elastic modulus in longitudinal direction
2	Elastic modulus in transverse direction (optional)
3	Tensile strength
4	Strain at tensile strength (if possible)

Table 1: Measurements for static tensile testing

Data field	Description / Units / Remarks
Optimat name	Unique ID of the specimen
Plate nr.	Given in doc. OB_TC_R011
Laboratory	
Thickness	[mm]
Minimum width	[mm]
Date of test (start/end)	Formatted dd.mm.yy
Test type	STT
F_max	Failure load, [kN]
e_max	Strain at failure load, [%]
s_max	Tensile strength, [MPa]
Failure mode	
Test speed	0.25 mm/min
Strain rate	[%/s]
Eit	Modulus in longitudinal direction, [GPa]
Test machine	
Control type	Load or displacement
Type of grips	
Clamping force	[kN]

Table 2: Required data to report for static tensile tests

5.3 Compression testing

Compression tests on the Optimat specimens are carried out according to ISO 14126 standard. Standard test machines with ydraulic or mechanical grips are to be used. For hydraulic grips, the applied grip pressure should be recorded. Mechanical equipment used for compression tests should limit initiation of bending or buckling as far as possible. Load has to be applied displacement-controlled and test speed amount to 1.0 mm/min. Strain in loading direction is measured with two strain gauges (recommended gauge length 6 – 10 mm) placed back to back on the specimen or with extensometer. Strain measurements should be set to zero before closing of the second clamp to determine initial bending of the specimen. According to ISO 14126 standard bending is defined as $\varepsilon_b = \left| \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} \right|$ and should not exceed a value of 10%. This condition has to be fulfilled for loads below 80% of the failure load. Elastic properties of undamaged material are measured within applied strain of 0.05%-0.25%.
The required measurements are given in Table 3 and the required information for reporting to OptiDat in Table 4.

No.	Description
1	Elastic modulus in longitudinal direction
2	Elastic modulus in transverse direction (optional)
3	Compressive strength
4	Strain at compressive strength (if possible)
5	Bending

Table 3: Measurements for static compressive testing

Data field	Description / Units / Remarks
Optimat name	Unique ID of the specimen
Plate nr.	Given in doc. OB_TC_R011
Laboratory	
Thickness	[mm]
Minimum width	[mm]
Date of test (start/end)	Formatted dd.mm.yy
Test type	STC
F_max	Failure load, [kN]
e_max	Strain at failure load, [%]
s_max	Tensile strength, [MPa]
Failure mode	
Test speed	1.00 mm/min
Strain rate	[%/s]
Eic	Modulus in longitudinal direction, [GPa]
Test machine	
Control type	Load or displacement
Type of grips	
Clamping force	[kN]
Remarks	Bending and any further important information

Table 4: Required data to report for static compressive tests

6 Test procedures for fatigue tests

The fatigue testing program of Optimat Blades includes constant amplitude tests (CA) as well as variable amplitude tests (VA). In the CA tests different types of laminates and specimens are used, whereas the VA tests are only part of work in Task Group 1 and therefore not be mentioned here.

6.1 General remarks

Each specimen has to be investigated by eye for any irregularities or damage. The alignment of the tabs has to be checked with a planar tool. Width and thickness of the specimens has to be measured with an accuracy of 0.01 mm.
All tests are accomplished force-controlled at predetermined load levels and testing frequencies, which are given in chapters 6.2 and 6.3. The laboratories, which are involved in the determination of these load levels are also referred to chapter 6.4. Except for the 90° lay-up of the UD specimen, where the load is defined in terms of stress, the load levels are given in terms of 'Load per unit width': Therefore this value has to be multiplied with the actual width of the specimen to derive the load for testing. Strain in the loading direction is measured with two strain gauges (recommended gauge length 6 – 10 mm) placed back to back on the sides of the specimen or with extensometer. Strain measurements should be set to zero before closing of the second clamp to determine initial bending of the specimen. Elastic properties of the undamaged material are measured within applied strain of 0.05% - 0.25% during the first load cycle using a testing frequency of 0.02 Hz. Load, displacement and stiffness are measured throughout the fatigue test if possible.
The measurement of the surface temperature of the specimen is recommended at least for one specimen at each load level. Temperature has to be measured continuously or periodic

with a thermocouple or any other suited measuring device at a specified location and shall not exceed the temperature limit of 35°C except for the temperature rise before failure. The measuring point is located nearby the tab line (approximately 5 mm distance) of the lower tabs. It has to be assured, that the temperature measurement is not influenced by environmental effects, such as air flow of a cooling fan. Anyway this measurement is not a measure for the temperature inside the specimen, since it is influenced by the friction between debonding tabs and the specimen. Furthermore the different types of measuring devices and exact conditions of the temperature measurement yield different results. Therefore an exceedance of the temperature limit is acceptable, unless it is a major exceedance (more than 10° C). In this case, the appropriate task leader has to be informed immediately.

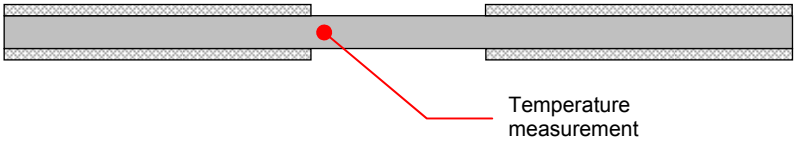

Figure 3: Temperature measurement Optimat specimen

The required information for reporting to OptiDat is given in Table 5. This is only the basic data necessary to describe any fatigue test. Depending on the exact testing procedure, as for residual strength tests for example, additional information is needed.

Data field	Description / Units / Remarks
Optimat name	Unique ID of the specimen
Plate nr.	Given in doc. OB_TC_R011
Laboratory	
Thickness	[mm]
Minimum width	[mm]
Date of test (start/end)	Formatted dd.mm.yy
Test type	CA
F_max	Applied load, [kN]
e_max	Strain at applied load, [%]
s_max	Stress at applied load, [MPa]
No. of cycles to failure	
Failure mode	
Test speed	[Hz]
Strain rate	[%/s]
Eic, Eit	Modulus in longitudinal direction, [GPa]
Test machine	
Control type	Load or displacement
Type of grips	
Clamping force	[kN]
Specimen temperature	[°C]
Remarks	Bending and any further important information

Table 5: Required data to report for fatigue tests

6.2 Load levels for Optimat MD specimen

The basic load levels and testing frequencies for the MD material are given in the following sections.

6.2.1 MD R=-1

The S-N curve is given through $\frac{F_{\max}}{w} = 3.7939 \cdot N^{\left(-\frac{1}{9.4933}\right)}\ (kN/mm)$.

Load level	Load cycles	Load [kN/mm]	Frequency [Hz]
1	5.000	1.55	0.86
2	50.000	1.21	1.44
3	1.000.000	0.89	2.57
4	10.000.000	0.69	4.39

Table 6: Load level definition MD R=-1

6.2.2 MD R=0.1

The S-N curve is given through $\frac{F_{\max}}{w} = 5.2419 \cdot N^{\left(-\frac{1}{9.9585}\right)}\ (kN/mm)$.

Load level	Load cycles	Load [kN/mm]	Frequency [Hz]
1	5.000	2.23	2.11
2	50.000	1.77	3.34
3	1.000.000	1.31	6.10
4	10.000.000	1.04	9.68

Table 7: Load level definition MD R=0.1

6.2.3 MD R=10

The S-N curve is given through $\frac{F_{\max}}{w} = 2.8356 \cdot N^{\left(-\frac{1}{28.8200}\right)}\ (kN/mm)$.

Load level	Load cycles	Load [kN/mm]	Frequency [Hz]
1	5.000	2.11	2.18
2	50.000	1.95	2.55
3	1.000.000	1.76	3.15
4	10.000.000	1.62	3.69

Table 8: Load level definition MD R=10

6.2.4 MD R=-0.4

Load level	Load cycles	Load [kN/mm]	Frequency [Hz]
1	5.000	2.39	0.63
2	50.000	1.36	1.95
3	1.000.000	0.88	4.64
4	10.000.000	0.63	9.02

Table 9: Load level definition MD R=-0.4

6.3 Load levels for Optimat UD specimen

6.3.1 UD 0° R=-1

The S-N curve is given through $\frac{F_{\max}}{w} = 3.73 \cdot N^{\left(-\frac{1}{8.040}\right)}\ (kN/mm)$.

Load level	Load cycles	Load [kN/mm]	Frequency [Hz]
1	5.000	1.29	1.23
2	50.000	0.97	2.17
3	1.000.000	0.67	4.56
4	10.000.000	0.50	8.09

Table 10: Load level definition UD 0° R=-1

6.3.2 UD 0° R=0.1

The S-N curve is given through $\frac{F_{\max}}{w} = 4.35 \cdot N^{\left(-\frac{1}{9.743}\right)}\ (kN/mm)$.

Load level	Load cycles	Load [kN/mm]	Frequency [Hz]
1	5.000	1.81	2.09
2	50.000	1.43	3.35
3	1.000.000	1.05	6.19
4	10.000.000	0.83	9.93

Table 11: Load level definition UD 0° R=0.1

6.3.3 UD 0° R=10

Not available at the moment.

6.3.4 UD 90° R=-1

Original definition:

The S-N curve is given through $\sigma_{\max} = 110.02 \cdot N^{\left(-\frac{1}{7.559}\right)}$ (MPa).

Load level	Load cycles	Load [MPa]	Frequency [Hz]
1	5.000	35.66	1.45
2	50.000	26.29	2.66
3	1.000.000	17.69	5.89
4	10.000.000	13.04	10.83

Table 12: Load level definition UD 90° R=-1

Newer definition using more results:

Load level	Load cycles	Load [MPa]	Frequency [Hz]
1	5.000	31.87	1.81
2	50.000	24.26	3.13
3	1.000.000	17.00	6.37
4	10.000.000	12.94	11.01

Table 13: Load level definition UD 90° R=-1

6.3.5 UD 90° R=0.1

Load level	Load cycles	Load [MPa]	Frequency [Hz]
1	5.000	41.59	1.78
2	50.000	31.85	3.03
3	1.000.000	22.51	6.06
4	10.000.000	17.24	10.33

Table 14: Load level definition UD 90° R=0.1

6.3.6 UD 90° R=10

Original definition:

Load level	Load cycles	Load [MPa]	Frequency [Hz]
1	5.000	139.48	3.30
2	50.000	127.71	3.94
3	1.000.000	113.87	4.96
4	10.000.000	104.26	5.92

Table 15: Load level definition UD 90° R=10

The S-N curve is given through $\sigma_{\max} = 193.25 \cdot N^{\left(-\frac{1}{26.12}\right)}$ (MPa).

Newer definition using more results:

Load level	Load cycles	Load [MPa]	Frequency [Hz]
1	5.000	138.63	3.35
2	50.000	126.11	4.04
3	1.000.000	111.49	5.17
4	10.000.000	101.42	6.25

Table 16: Load level definition UD 90° R=10

6.4 Determination of load levels and frequencies

This section is only designated for the laboratories, which determine the load levels and testing frequencies. All other laboratories are restricted to use this section!
The load levels and testing frequencies are determined using a preliminary S-N curve using 6 valid test results. In case of large scatter additional specimens should be used to increase the reliability. The testing frequencies should be as high as possible without overheating the specimen. Therefore the surface temperature of the specimen has to be measured according the definitions in 6.1 among the restriction, that an exceedance of the temperature limit is not allowed. The testing frequencies at a certain load level are determined using the constant energy approach (energy ~$f \cdot \varepsilon^2$) [2]. The underlying reference temperature and reference load should be determined at a high load level.
After the establishment of the preliminary S-N curve four load levels and the corresponding testing frequencies have to be reported to the authors of this specification. The definition of the S-N curve uses 'Load' as independent variable. The load levels are to be given in terms of 'Load per unit width' and should result in a fatigue life of 1.000, 50.000, 1.000.000 and 10.000.000 load cycles.

7 References

[1] Torben K. Jacobsen, *Reference material (Optimat) - Glass-Epoxy material*, LM Glasfiber A/S, doc. OB_SC_R001 rev. 1, 29.01.2003

[2] Olaf Krause, *Frequency effects on lifetime*, DLR, doc. OB_TC_N003 rev. 1, 19.12.2002

[3] Theodore P. Philippidis, *Static and fatigue tests of OB UD coupons at 0° and 90°*, UP, doc. OB_TG2_O002, 19.12.2003

[4] Theodore P. Philippidis, Theoni T. Assimakopoulou, *Comments on SN curve definition. Standard unidirectional OB coupons at 90° (R=-1 and R=10)*, UP, doc. OB_TG2_N002 rev. 0, 04.03.2004

[5] Theodore P. Philippidis et al., *Static and Fatigue tests on the standard OB UD coupon*, UP, doc. OB_TG2_R013 rev. 0, 17.07.2003

[6] Olaf Krause, *Fatigue Tests of OPTIMAT MD coupon*, DLR, doc. OB_TG1_R010 rev. 0, not yet published.